Noise Reduction Effect of Porous Elastic Road Surface and Drainage Asphalt Pavement

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A porous elastic road surface (PERS) is a pavement which main materials are rubber chip and polyurethane. Its acoustical absorption characteristics and flexibility makes it superior for noise reduction of highway compared to drainage asphalt pavement (DAP) .

Since 1994 we have been engaged in research and development of PERS, and have verified its effect on noise reduction and its durability as pavement. We have now proceeded to evaluate PERS on highways. We have already reported the result of the noise measurements at the first test construction . Due to the insufficient length of the first test construction, i.e. only 20m, the measurements of sound power levels (Lw) were limited to passenger cars and light trucks.

In this report, we have measured Lw of passenger cars, light to heavy trucks and busses. Firstly we evaluated the influence of the safety fences on the noise measurements at each test section by measuring Lw for test vehicles with and without fences present. Secondly we measured Lw from passing vehicles that traveled at constant or nearly constant speed conditions selected from the traffic stream. The noise reduction effect of the DAP and PERS passenger cars and light trucks 4-7dB and 7-11dB, respectively. For medium to heavy trucks and busses corresponding values are 2-5dB and 5-8dB, respectively.

INTRODUCTION

A porous elastic road surface (PERS) is a pavement which main materials are rubber chip and polyurethane. Its acoustical absorption characteristics and flexibility makes it superior to drainage asphalt pavement (DAP) for noise reduction of highway traffic. The noise reduction is defined as the difference in sound power levels between these low noise pavements and dense asphalt pavement (DENAP) in this paper.

Since 1994 we have been engaged in research and development of PERS, and have verified its effect on noise reduction and its durability as pavement. We have evaluated PERS in the research laboratories and on the test track of the Public Works Research Institute (1). However, it was difficult to reproduce typical traffic conditions on the test track, and it was impossible to verify both the long-term durability of the pavement, and the development of the skid resistance of PERS. We have now proceeded to evaluate PERS on highways. We have already reported the results of the noise measurements at the first test construction (2). In that report, we defined the noise reduction effect as the difference in sound power level (Lw) of individual vehicles. Due to the insufficient length of the test construction, i.e. only 20m, the measurement of Lw was limited to small sized vehicles, e.g. passenger cars and light trucks.

In this report, we have measured not only Lw of small sized vehicles but also Lw of large sized vehicles, e.g. medium to heavy trucks and busses. The test construction is consisted of six sections, a 170 m long dense graded asphalt concrete pavement, DENAP, as a reference pavement; a 80 m long double-layered drainage asphalt pavement, DDAP, a 50 m long single-layered drainage asphalt pavement, SDAP, and three 50 m stretches of porous elastic road surfaces,PERS#1-3, .

Table 1 describes the specifications and ages of these pavements at the test site. The base course of DENAP, SDAP, and DDAP was a coarse-graded asphalt mixture. The base course of PERS#1-#3 was a semi-flexible pavement. Semi-flexible pavements have relatively high durability against rutting and are usually used for bus stop areas. The results of adhesive tests on PERS have shown that a combination of an epoxy resin and a concrete base course e.g. a semi-flexible pavement has the best performance. The shorter curing time of semi-flexible pavements compared to that of conventional concrete pavements is the reason why we selected it as a base course for PERS.

DDAP is a special drainage asphalt pavement mainly focused on noise reduction. The smaller size of aggregate and higher porosity of upper layer compared to the bottom layer is expected to reduce both the tire-pavement noise and the mechanical noise. SDAP has become very popular and covers about 10-20 percent of urban arterial highways in Japan. DDAP is not regularly used in Japan. PERS is even lesser known than DDAP.
The PERS constructed at the test site are classified into two types, i.e. on-site construction type (ONSITE) and prefabrication type (PREF). PERS#3 is ONSITE as the conventional pavements, i.e. DENAP, SDAP, and DDAP. The contractor mixed the polyurethane binder, the rubber granules, and other additives with a mixer truck. A special finisher spread the mixture and completed the surface layer. PERS#1 and #2 belong to PREF as pre-cast concrete pavement. The PERS tiles were manufactured in a factory. The size of the panels were 1m long ×1m wide×0.03 m thick. The contractor does only the adhesive work that they put the panels on the base course with an epoxy type of adhesive. These three types of PREF were manufactured by different rubber product manufactures. These products have small differences in polyurethane resin as binder and additives for increasing durability and surface skid resistance.

The PREF did show better performance than the ONSITE. The curing time of PREF was one day, while the curing time of ONSITE was one week. These curing times are those of the summer season. They are influenced by temperature and humidity. The tensile strength of PREF, which is seems to be a durability factor, were twice that of the tensile strength of the ONSITE. The porosity of PREF was about 40% and the porosity of ONSITE was 30%. The lack of joints seems to be the only advantage of ONSITE compared to PREF.

Initially we measured Lw of test cars at each section, with and without the safety fences present, to identify the influence of the safety fences on the noise measurement. It was identified that the error caused by the safety fences was within the mechanical error of sound meter, and could be ignored. We used the same noise measurement system as to the test cars to normal vehicles that passed the measurement system under constant or nearly constant speed and that were not disturbed by noise from other vehicles. Finally the noise reduction effect of PERS was calculated as the difference of this Lw compared to the Lw of DENAP.

FIELD MEASUREMENT AND DATA ANALYSIS

In September 2003, the test construction of was completed on the national highway route 23 in Tsu, Mie prefecture. This was the second test construction on a public road in Japan. The first test construction (2) has been already removed. Fig. 1 shows the allocation of the pavements constructed. We set a sound level meter (SLM) as a microphone at the shoulders of the each differently paved section. We measured and analyzed the sound levels and calculated Lw. We used the finite-length square-integrating technique (3) to work out Lw. We categorized each Lw according to the vehicle type, i.e. to small vehicles and large vehicles as Table 2 shows. The regression analysis finally determined Lw classified by the vehicle type.

For the traffic measurements, we put a video camera at the SDAP section and had continuous shots of the running vehicles at this section, assuming that it represented the traffic condition at all sections. We analyzed the video and computed traffic volume and speed every 10 minutes.

Besides these measurements, we measured the motor vehicle Lw before and after taking away safety fences, and calculated the difference in the Lw to determine the influence of safety fence on Lw. There were two types of safety fences, a plate type and a pipe as shown in Fig. 1 and 2. The safety fences caused reflection and diffraction of the sound propagation, and influenced on the noise measurements. The plate type of safety fence intuitively seemed to be more influential than the pipe type because of their shape. As illustrated in Fig. 3, we set a precision SLM just 70cm above the top of the safety fence.

It was necessary to determine the influence of the safety fence on noise measurements before measuring noise. We used a heavy truck and a passenger car as test vehicles. We fixed the running speed and gearshift position, influential on the motor vehicle Lw, and measured passing-by noise. We measured the difference in Lw with and without the safety fences. As described in Fig. 4, we put a photo-detector, which was composed of a light-source and a detector, 10m behind and a head of the noise measurement point to measure the location and running speed of the test vehicles.

By using the signal from the photo-detectors, eqns. 1-4, we calculated the average running speed $\bar{v}$, acceleration α, length of the vehicles l, and the time when the center of the vehicle pass the microphone t_c.

$$\bar{v} = v_0 + \alpha t_c \qquad (1)$$

$$\alpha = \frac{2}{t_2} \frac{t_1 + t_2 - t_3}{(t_1 - t_3)(t_2 - t_1 - t_3)} L \qquad (2)$$

$$l = \frac{t_1}{t_2} \frac{(t_3 - t_2)(t_2 + t_3 - t_1)}{(t_3 - t_1)(t_3 + t_1 - t_2)} L \qquad (3)$$

$$t_c = \frac{\sqrt{v_o^2 + \alpha(L + l)} - v_0}{\alpha} \qquad (4)$$

t_1 : ending time of shielding the forward photo detector

t_2 : starting time of shielding the backward photo detector

t_3 : ending time of shielding the backward photo detector

□:distance between the forward and backward photo detector (=20m)

The starting time of shielding the forward photo detector is t=0.

The test vehicle's steady speed run is defined as its measured acceleration within ±1m/s^2. We recorded the AC output signal of the sound level meter and the signal of the photo detectors onto a digital data recorder and used the finite length square-integrating technique (3) to work out Lw from the noise data

There are two common ways to calculate the vehicle power level from the sound pressure levels, the peak level method (PLM) and the more accurate square integrating technique (SIT). We have introduced a new method based on the SIT and called it the "finite square integrating method" (FISIM). It is described by equation (5-7), which is derived in the Appendix. The basic equation of FISIM is as follows:

$$Lw = 10\log_{10}\frac{\bar{I}}{I_0} + 11.0 + 20\log_{10}\frac{r_{CL}}{r_0} - L_\beta \qquad (5)$$

where

$$L_\beta = 10\log_{10}\left(\beta \arctan\frac{1}{\beta}\right) \qquad (6)$$

and

$$\beta = \frac{2r_{CL}}{vT_m} \qquad (7)$$

Here $\bar{I}$ is the average sound intensity, $I_0 = 10^{-12}(W/m^2)$, r_{CL} expresses the minimum distance to the centerline, $r_0 \equiv 1(m)$, v is the vehicle speed (m/s) and $T_m = 1.0(s)$. Figure illustrates the measurement conditions and shows the geometry of experiment.

We measured the vehicle power level for the test vehicles at three speeds: 40km/h, 50km/h and 60km/h. Fig. 5 shows the difference in of Lw with and without the safety fence. We found out it was within±1dB in both the cases of DENAP and two types of DAP. It also means that the error caused by the safety fences is within the mechanical error of SLM, and can be ignored.

Disregarding the acceleration of the normal vehicles, we used all the data of the normal vehicles to do regression analysis of Lw. We documented that both the test vehicles and the normal vehicles were under the condition of single vehicle pass by, when we only detected the target vehicle signals by all the twelve photo-detectors set in the zone of test construction. If we detected a signal of other vehicles, we discarded all the data of the target vehicle.

RESULT

We categorized the Lw from the analysis into two kinds of the normal vehicles, as Fig. 6 shows.

The difference in the Lw of the normal vehicles between DENAP, DDAP, SDAP, and PERS#1-3 are presented in Fig 7. What is very interesting here is that the differences in the Lw of PERS become higher as the running speed increases. This tendency is remarkable especially for the large-sized vehicles.

We finally found that the noise reduction effect of the DAP on small cars and on large cars are 4-7dB and 2-5dB, respectively, while the noise reduction effect of PERS are 7-11dB and 5-8dB, respectively for the same categories of vehicles

CONCLUSION

We categorized the Lw of the two kinds of the normal vehicles from the analysis. Moreover, we have showed the difference in the Lw of the normal vehicles between DENAP, DDAP, SDAP, and PERS#1-3. What is very interesting here is that the differences in the Lw of PERS become higher as the running speed increases. This tendency is remarkable especially in the large-sized vehicles. Noise reduction effect of the DAP on small cars and on large cars are 4-7dB and 2-5dB, respectively, and those of PERS are 7-11dB and 5-8dB, respectively.

ACKNOWLEDGEMENTS

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APPENDIX

We are interested in determining the sound power, *W*, in terms of the measured sound intensity *I*, at a distance *r* from the non-directional point sound source, in a free sound field is given by:

$$I = \frac{p^2(t)}{\rho c} = \frac{W}{4\pi r^2} \qquad \text{(A1)}$$

where

$p^2(t) =$ mean square sound pressure (Pa^2)
$\rho =$ density of air (kg/m^3)
$c =$ sound speed in the air (m/s)

When the sound source moves along a line with the speed *v*, as shown in Figure, the distance *r* can be expressed in terms of r_{CL}, the minimum distance to the centerline, and time *t*:

$$r = \sqrt{v^2 t^2 + r_{CL}^2} \qquad \text{(A2)}$$

Here we take $t = 0$ to be the time of closest approach. Combining equations (A1) and (A2), we find the following relationship between the measured mean square sound pressure and time:

$$\frac{p^2(t)}{\rho c} = \frac{W}{4\pi\left(v^2t^2 + r_{CL}^2\right)} \qquad \text{(A3)}$$

By integrating the square of the sound pressure over the time interval of measurement, T_m, we get the average measured sound intensity, $\bar{I}$:

$$\bar{I} = \frac{\frac{1}{T_m}\int_{-T_m/2}^{T_m/2} p^2(t)dt}{\rho c} = \frac{W}{4\pi r_{CL}^2}\left(\frac{2r_{CL}}{vT_m}\right)\arctan\left(\frac{vT_m}{2r_{CL}}\right) \qquad \text{(A4)}$$

Equation (A4) reduces to the SIT formula for very long observation times, as T_m goes to infinity. Diving both sides of equation (A4) by $I_0 = W_0 / r_0^2$, where $W_0 \equiv 10^{-12}(W)$ and $r_0 \equiv 1(m)$, we get:

$$\frac{\bar{I}}{I_0} = \frac{W}{W_0} \cdot \frac{1}{4\pi\left(r_{CL}/r_0\right)^2} \cdot \beta \arctan\frac{1}{\beta} \qquad \text{(A5)}$$

where

$$\beta = \frac{2r_{CL}}{vT_m} \qquad \text{(A6)}$$

Taking the common logarithm and multiplying by 10, we get:

$$10\log_{10}\frac{\bar{I}}{I_0} = 10\log_{10}\frac{W}{W_0} - 11.0 - 20\log_{10}\frac{r_{CL}}{r_0} + L_\beta \qquad \text{(A7)}$$

where

$$L_\beta = 10\log_{10}\left(\beta \arctan\frac{1}{\beta}\right) \qquad \text{(A8)}$$

Then, the sound power can be expressed in the terms of the integrated measured intensities, as follows:

$$L_W = 10\log_{10}\frac{W}{W_0} = 10\log_{10}\frac{\bar{I}}{I_0} + 11.0 + 20\log\frac{r_{CL}}{r_0} - L_\beta \qquad \text{(A9)}$$

Note that the correction term L_β contains all characteristics of the vehicle's motion, r_{CL}, v and the measuring time, T_m, $\Theta = \arctan\frac{1}{\beta}$ is the angle shown in Figure. Note the following limits:

When $\beta \to \infty$, $\Theta \to 0$, and $L_\beta \to 0$ (A10)

When $\beta \to 0$, $\Theta \to \frac{\pi}{2}$, and $L_\beta \to -\infty$ (A11)

Equation (A10) shows that for a short value of vT_m and/or for long r_{CL}, the effect of the vehicle movement becomes negligible. In such a case $L_\beta = 0$, and eqn (A9) reduces to that of the peak level method (PLM). However, eqn (A11) indicates that for a large value of vT_m and/or short r_{CL}, the correction term cannot be neglected.

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Tables & Figures

Table 1

Pavement	Base Course (thick-ness: cm)	Surface						Note
		Thickness (cm)	Binder (%)	Aggregate (mm)	Porosity (%)	Age (year)	MPD (mm)	
DENAP	Coarse-graded asphalt mixture (5+5=10)	5	Asphalt (5%)	20-0	-	1	0.20	
SDAP		5	High viscosity modified asphalt (5%)	13-5	20	1	0.35	
DDAP		2(upper) + 3(lower)	High viscosity modified asphalt (5%,upper & lower)	5-3 (upper) + 13-5 (lower)	25(upper) + 20(lower)	1	0.70	
PERS #1	Semi-flexible pavement (5cm) +Coarse-graded asphalt mixture (5+5=10)	3	Polyurethane (15%)	3-1	40	0.25	0.44	On-site construction
PERS #2		3	Polyurethane (15%)	3-1	40	0.25	0.35	Prefabrication type
PERS #3		3	Polyurethane (15%)	3-1	30	0.25	0.32	Prefabrication type

MPD: Mean Profile Depth measured at wheel path by the methodology based on ISO 13473-1 “Characterization of pavement texture by use of surface profiles -- Part 1: Determination of Mean Profile Depth” and/or ASTM E1845-01 “Standard Practice for Calculating Pavement Macro-texture Mean Profile Depth”.

Table 2

Classification	Car Type	Specification
Small Vehicle	Passenger Car	Vehicle which passenger capacity is less than 10
	Light Truck	Truck which displacement more than 50(cc) and length is less than 4.7(m)
Large vehicle	Middle Truck	Truck which length is more than 4.7m, total vehicle weight is less than 8(t), and the maximum loading weight is less than 5 (t)
	Middle Bus	Bus which passenger capacity is from 11 to 29
	Large Truck	Truck which total vehicle weight is more than 8(t) or the maximum loading weight is more than 5 (t)
	Large Bus	Bus which passenger capacity is more than 30
	Large Special Vehicle	Fire engine truck, Heavy Tractor with long trailer, etc.

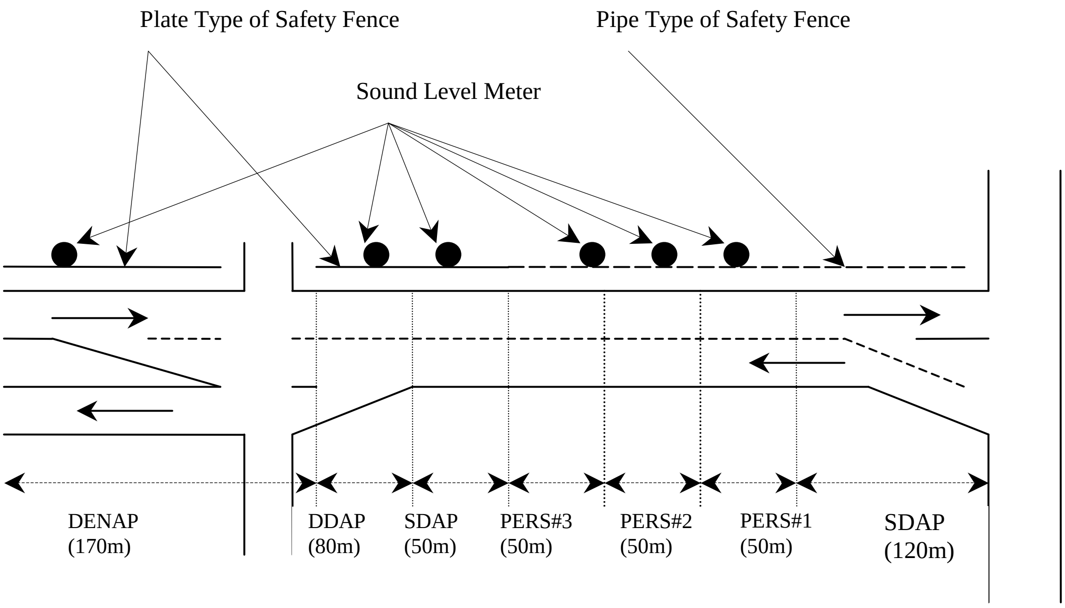


Fig.1 Pavement allocations


(a) Plate Type

(b) Pipe Type

Fig. 2 Safety fence

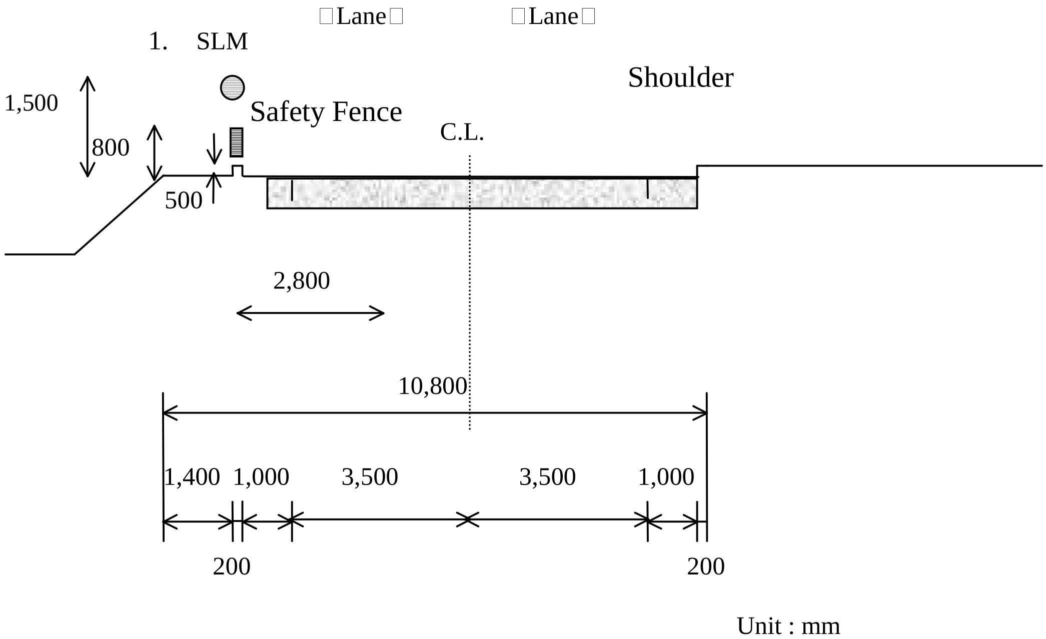


Fig. 3 Cross-section of noise measurement point

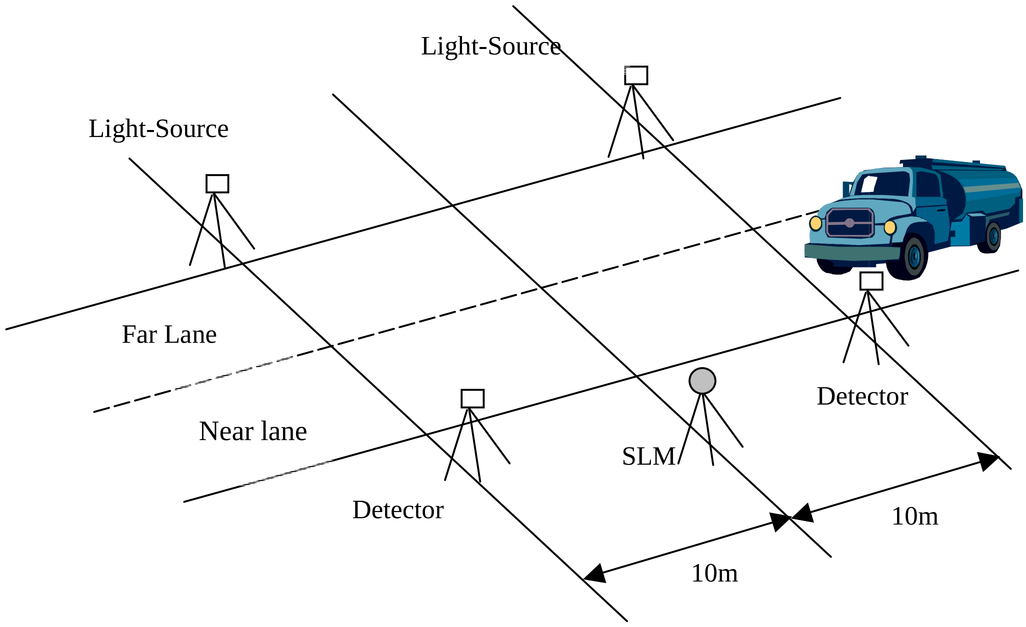
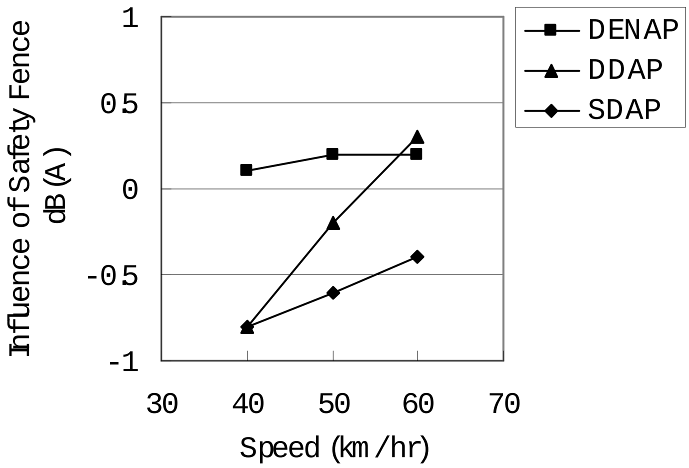
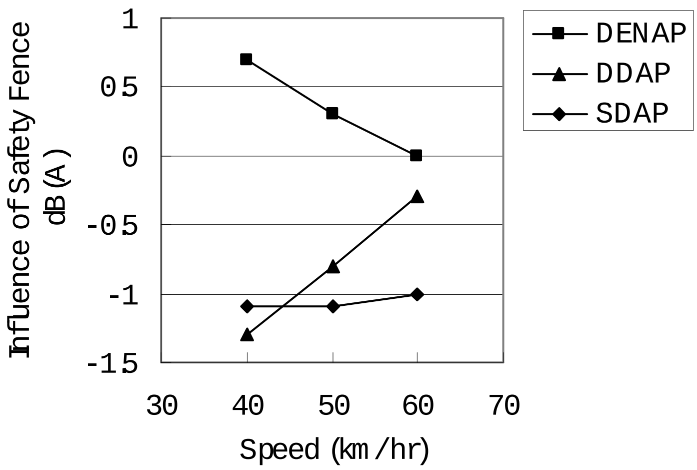


Fig. 4 Photo detector allocations

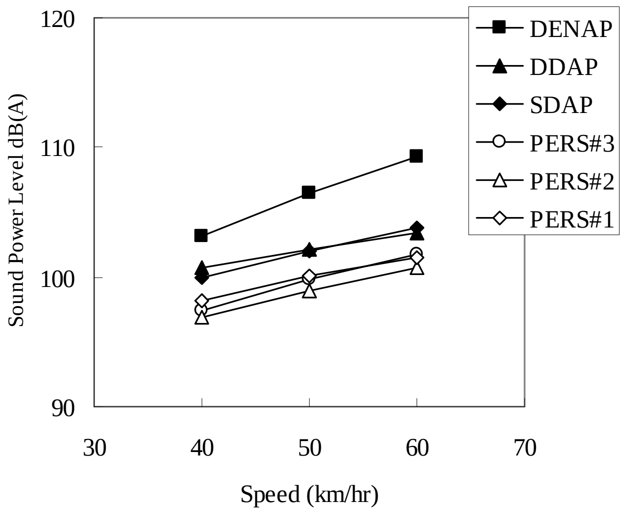


(a) Large Truck

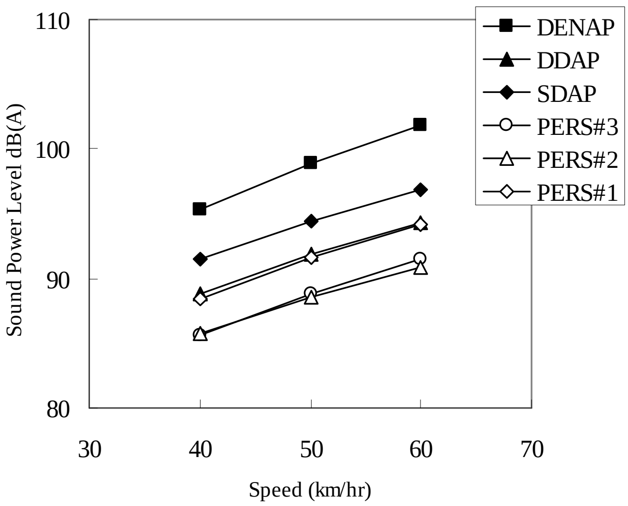


(b) Passenger Car

Fig. 5 Influence of safety fence on noise measurement

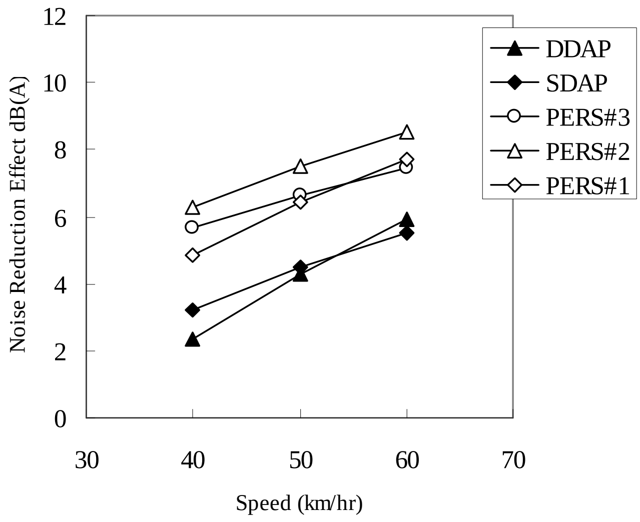


(a) Large Vehicle

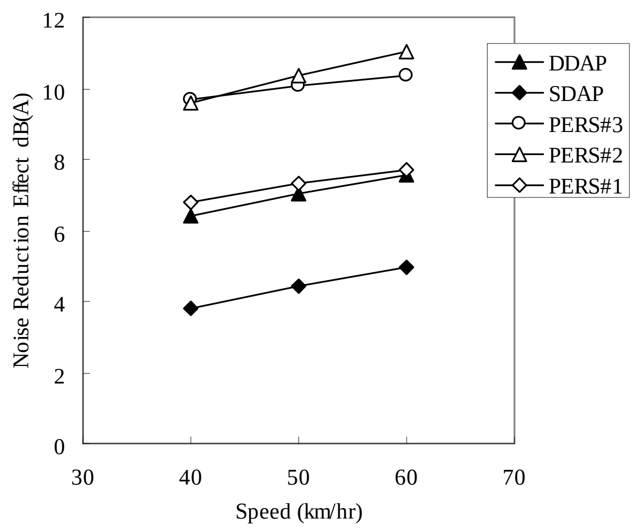


(b) Small Vehicle

Fig. 6 Sound power level



(a) Large Vehicle



(b) Small Vehicle

Fig. 7 Noise reduction effect described in sound power level